

# **SSEP MONITORING IN ANEURYSM SURGERY**

**Dissertation submitted to the Dr. M.G.R. Medical  
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# **CERTIFICATE**

This is to certify that this study ' SSEP monitoring in aneurysm surgery' is a bonafide work of Dr. Tony Abraham Thomas and is submitted in fulfillment of the M.Ch. Neurosurgery examination conducted by the Dr. MGR Medical University, Chennai in August 2008.

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# **SSEP MONITORING IN ANEURYSM SURGERY**

## **ABSTRACT**

### **Introduction and objectives:**

This study evaluated the usefulness of somatosensory evoked potentials (SSEPs) for the monitoring of perfusion of a selected arterial territory during temporary arterial occlusion. Perioperative changes in amplitude of SSEPs were correlated with postoperative neurological function.

### **Methods:**

This was a prospective study of 47 patients who underwent clipping of anterior circulation aneurysms utilizing SSEPs for neurophysiological monitoring. Statistical analysis was done for 46 procedures where a temporary clip was applied for proximal control before application of the permanent clip. Decrease in amplitude of evoked potentials by 50% or more was considered a 'significant change'. The motor status of a patient both pre and postoperatively was compared and correlated with intraoperative changes in amplitude. A 'significant change' in amplitude which did not revert to its baseline value was considered a positive test and a patient with a new postoperative deficit was considered a positive end point.

### **Results:**

Nine of the 46 procedures (19.5%) monitored with SSEPs had a significant decrease in amplitude after application of a temporary clip. In all cases, the amplitude reverted back to baseline value after removal of the clip. Three

patients had new post operative motor deficits. Of these, two patients had a significant change in amplitude. The calculated specificity was 100% and negative predictive value was 94%. There was a greater proportion of MCA aneurysms (30.7%) that showed a significant change in amplitude compared to ACA (16.6%) and posterior communicating artery aneurysms (16.7%). The prevalence of significant change (out of the total number of clip applications) was greater in middle cerebral artery aneurysms (27.3%) compared to anterior cerebral artery (4.25%). There was no significant difference in the prevalence between ACA aneurysms with or without collateral supply from the opposite side (4.3% and 5% respectively). The average time taken for recovery to baseline following a decrease in amplitude was more than twice as long in ACA aneurysms without collateral supply ( 9 minutes ) than those with collateral supply (4 minutes). Intraoperative rupture of aneurysm was found to be associated with a higher average decrease in amplitude (61.5%) and prevalence of SSEP change (45.5%) than any other subgroup.

## **Conclusions:**

SSEP monitoring during intracerebral aneurysm surgery has a high negative predictive value and specificity. Absence of a 'significant change' in amplitude during surgery is a good predictor of favourable outcome. Middle cerebral artery aneurysms show a greater propensity to produce ischaemia following temporary clip application compared to other arterial territories.

# **SSEP MONITORING IN ANEURYSM SURGERY**

## **INTRODUCTION**

Temporary arterial occlusion is an established technique in the repair of intracranial aneurysms. The use of temporary clip occlusion allows for decreasing the pressure and size of the aneurysm to facilitate dissection, opening the aneurysm to remove calcific or atheromatous material from the neck, and reconstructing a parent vessel from a broad based aneurysmal neck. The most compelling reason for the use of a temporary clip is that it may decrease the risk of intraoperative aneurysm rupture, a peroperative complication associated with significant morbidity and mortality. Batjer and Samson <sup>1</sup> reported in a series of 307 patients that intraoperative rupture occurred in 19% of surgeries. This was associated with a morbidity of 22% and mortality rate of 16%, which was a threefold increase in the incidence of serious complications. The temporary clip may be applied proximal to the aneurysm in the parent artery or distal to the aneurysm. By decreasing the pressure in the aneurysm, a turgid aneurysmal sac threatening rupture during handling is converted into a more pliable structure, amenable to and facilitating safe dissection to delineate the neck before application of the permanent clip.



However temporary clipping carries with it the risk of hypoperfusion to the territory supplied by the artery occluded. This is also true for permanent clipping, where a post-operative deficit secondary to inadvertent occlusion of a major vessel or small perforating artery remains a feared complication. An intraoperative monitoring technique that would provide an accurate warning of cerebral ischaemia would, theoretically, reduce the incidence of these problems. Physiological monitoring that can act as an indicator of cerebral perfusion and its compromise becomes therefore, an important adjunct to the surgical procedure.

Several monitoring techniques have been described in literature. Monitoring of evoked potentials like SSEPs is a safe and non-invasive monitoring modality.

### **AIM OF THE STUDY:**

To evaluate the usefulness of somatosensory evoked potential (SSEP) monitoring during intracranial aneurysm surgery in predicting and preventing postoperative morbidity.

## **OBJECTIVES:**

1. To assess the correlation between change in amplitude of SSEP and the neurological status post operation.
2. to assess the influence of factors like grade of subarachnoid haemorrhage, collateral blood flow, anatomical abnormalities on postoperative neurological status and SSEP changes.

## **Methodology**

SSEPs monitored for 47 surgeries for intracranial aneurysms performed at the Christian Medical College between March 2004 and May 2008. All patients above the age of 12 years with intracranial aneurysms involving the anterior circulation, who present with subarachnoid haemorrhage or other symptoms or with aneurysm detected incidentally. Only elective procedures performed during working hours were monitored. Subarachnoid haemorrhage was graded according to the Fisher grade from the preoperative CT scans. Digital subtraction angiograms were used to assess the anatomy of the aneurysm and the circle of Willis and collateral blood supply to the side of the aneurysm. Motor examination of the patient was done pre and postoperatively in the immediate post operative period and on the seventh postoperative day. Only decrease in motor power was considered as criterion for postoperative neurological deficit.

The SSEP findings were categorized according to the following classification:

Type 1 – no significant change in amplitude

Type 2 – significant decrease in amplitude with complete recovery to baseline.

Type 3 – significant decrease in amplitude with partial recovery to baseline.

Type 4 – complete flattening of wave forms with no improvement.

Type 5 – flat waveforms from the beginning of surgery.

### **Definition of terms:**

Significant decrease in amplitude – Decrease in amplitude by 50% or more from the baseline amplitude following temporary clip application on the parent artery.

Post operative deficit – Motor deficit observed within 24 hours post surgery.

### **Statistical analysis:**

Each patient related characteristic and technical parameter of temporary arterial occlusion was analyzed in relation to the end point of the development of radiographic evidence of post operative motor deficit in an attempt to identify the

clinical or technical factors associated with the development of post operative deficit in the vascular territory subjected to temporary clipping. The end point of a significant decrease in amplitude was also analyzed. Univariate and multivariate analysis was conducted. Categorical variables were compared using the chi-square test and continuous variables were compared using the t-test when appropriate. Differences with a probability value of less than 0.05 were considered statistically significant. SPSS software was used for statistical calculations with the help of clinical statisticians.

### **Monitoring methods technical aspects:**

SSEPs were evoked by stimulating the contralateral median nerve at the wrist for monitoring the middle cerebral artery (MCA) territory. Cortical SSEP monitoring of the anterior cerebral artery (ACA) territory was accomplished by stimulating the contralateral posterior tibial nerve at the ankle. A 'Nicolet Pathfinder' machine was used to obtain evoked potentials. Standard surface EEG electrodes were used and placed according the international 10-20 system. A frontal reference (FZ) was used. Constant current stimulation of 0.3 ms duration was delivered. Simulation intensity set a little above motor threshold. Electrical stimuli were produced at a rate of 4.7 Hz. Sweep time was 50 ms (median nerve) and 100 ms (posterior tibial nerve). Hundred to two hundred and fifty responses were averaged depending on the quality of the waveforms obtained.

For analysis of SSEP recordings, amplitude of the cerebral evoked responses was used. Significant change in amplitude was defined as a reduction in amplitude by 50% or more. The amplitude of the last recording before the application of the clip was considered as the baseline. Recording of SSEPs was done during the course of the surgery. After application of the temporary clip, readings were recorded every one minute. The duration of the clipping and nature of the readings was conveyed to the surgeons at regular intervals. The concentration of isofluorane was kept constant during the period of temporary clipping.

In the instance of the amplitude of the recording decreasing to 50% or lesser than the baseline, the surgeon was immediately informed and the temporary clip removed.

# **LITERATURE REVIEW**

## **Effects of ischaemia and experimental investigation of ischemic thresholds**

The rationale for employing SSEPs is the strong correlation between electrophysiological changes and regional cerebral blood flow. Several electrophysiological studies have demonstrated the relationship of neuronal function, viability and critical flow thresholds.

Primate studies <sup>2</sup> have shown that SSEPs are maintained at levels of rCBF (regional cerebral blood flow) >16 ml/100 g/ min but are absent at levels below 12 ml/100 g/ min. At rCBF levels between 14 and 16 ml/100 g/ min there is a sharp reduction in the cortical SSEP amplitude (50%) when compared with baseline. Ischaemia also prolongs the central conduction time (CCT) > 10 ms with an rCBF of about 15 ml/100 g/ min. As rCBF decreases further infarction results. Chronic stroke models in primates <sup>3</sup> disclosed areas of infarction corresponding to rCBF of 10 - 12 ml/100 g/ min or less after MCA occlusion for 48 hours. These studies suggest that a 50% reduction in amplitude of the SSEP or a prolongation of CCT more than 10 ms corresponds to a rCBF of 14-16 ml/100 g/ min and is indicative of ischaemia and possible progression to infarction.

The effect of ischaemia on the brain at the cellular level is not uniform and there are various factors that govern the response to an ischaemic insult. Sensitivity to ischaemia differs according to cell type. Neurons are the most sensitive, followed by glial cells and endothelial cells. Studies have shown that after brief periods of global ischaemia, during which no histological damage was initially seen, definitive cell damage appeared later. This type of ischaemic damage has been termed delayed neuronal necrosis.

The type of ischaemia (global or focal) also affects the response to it. Neurons tolerate greater periods of ischaemia following a global decrease in blood flow. Focal ischaemia on the other hand results in irreversible damage very quickly, after as little as 10 minutes. This has important implications in the period of temporary clip application following a significant change in SSEP recordings.

Focal ischaemia affecting only one or two vessels and therefore a small part of the brain results in two distinct perfusion zones. The ischaemic core is the most affected region. The zone surrounding it with a relatively higher flow as determined by the nature and extent of collateral channels surrounds the ischaemic core. This has clinical significance in that these cells are viable even though they are electrophysiologically silent and can therefore be salvaged, thus minimizing the extent of damage and clinical neurological deficit. Several models of MCA occlusion have shown that reperfusion within 30 minutes of the onset of ischaemia decreases the extent of permanent damage and restores its electric activity and ionic homeostasis.

In the progression of acute cerebral ischaemia, **a failure of electrical activity precedes the deterioration of ionic homeostasis**; electrophysiological monitoring should logically be an important tool in predicting the development of cerebral ischaemia *before* irreversible damage ensues <sup>4</sup>.

### **What are evoked potentials?**

Evoked potentials are the electrical manifestation of the brain's reception of and response to an external stimulus. Somatosensory evoked potentials can be generated by electrical stimulation of a peripheral nerve. The evoked electrical activity, depicted in the form of waves, can be detected from the skin or from deeper surfaces if invasive electrodes are used. Differential amplification is applied to improve the signal to noise ratio of the monitored activity. These waveforms have to be separated from background electrical activity of the brain (EEG). This is done by computerised averaging. This is possible since the electrical response of the brain to the stimulus always comes at the same interval of time (time locked event) after the stimulus (whereas the other activities present are not coupled to the stimulus) and computers can be used to extract the desired signal. Stimuli are given repetitively and the computers averages the new data acquired after each stimulus, with the averaged results from previous stimuli stored in its memory. The process is continued until the desired waveform becomes sufficiently clarified.



Amplitude in evoked potentials is usually stated in micro volts. This can be measured by three methods:

1. baseline to peak
2. peak of one polarity to the immediately following peak of the opposite polarity
3. Area under the peak.

The first two are commonly used and the amplitude obtained is called the 'absolute amplitude'. The second method was used in this study.

The term latency commonly refers to the time interval between the stimulus and a specific point in the evoked potential waveforms. This is usually measured in milliseconds.

Amplitude measurements have been the most useful when used in comparison with the same measure on the other side of the subject, that is, when subjects or cases serve as their own controls. The amplitude difference is expressed as proportionality ("percentage change"). Most clinical trials have used amplitude alone or along with central conduction time, to quantify the change in SSEPs during an ischaemic event. They have reported that posterior tibial nerve stimulation is appropriate for aneurysms of the anterior cerebral complex because the anterior cerebral artery supplies the areas of the somatosensory cortex supplying the leg and foot. Median nerve SSEPs have been suggested as the ideal source for monitoring during surgery of middle

cerebral artery aneurysms because the MCA supplies the area of the somatosensory cortex that controls the hand.<sup>5 6</sup>

The stimulus intensity used for obtaining somatosensory evoked potentials excites only the largest myelinated fibers in the peripheral nerve (cutaneous and subcutaneous somaesthetic and proprioceptive fibres and alpha motor axons). Cell bodies of the large fiber dorsal column sensory system lie in the dorsal root ganglia; their central processes travel rostrally in ipsilateral posterior columns of the spinal cord and synapse in the dorsal column nuclei present at the cervicomedullary junction. Second order fibers cross to the opposite side shortly after origination and travel to the primary receiving nucleus of the thalamus (ventral posterolateral nuclei) via the medial lemniscus. Third order fibers continue from the thalamus to fronto parietal sensorimotor cortex. SSEPs are therefore a function of both cortical grey matter and the underlying white matter pathways.

The evoked potentials are following stimulation of a peripheral nerve are expressed in the form of waves about a baseline. A wave with an upward deflection is a negative wave (N) and a downward deflection is termed a positive wave (P). Only certain standard and constant waves are considered for evaluation. For example, the waves considered for a median nerve stimulation are N20 and P25, and those for a tibial nerve stimulation are P37 and N45. The numbers beside the wave type denote the latency of the wave, i.e., the time in milliseconds for the wave to develop from the point of stimulation.

## **Intraoperative factors that affect SSEPs**

There are some intraoperative factors that can alter evoked potential readings and thus act as confounding factors during recording.

Temperature can substantially change SSEP recordings. Over the course of the surgery it is common for the patient's core temperature to drop to a low degree. Limb temperature often drops more than the core temperature.

Hypothermia can cause the amplitude of potentials to become very low or even disappear and can prolong latencies. We attempt to maintain a uniform temperature during surgery using external electric blanket warmers.

Hypotension can cause some changes in potentials. Evoked potentials seem relatively stable at systolic pressure as low as 80mmHg. Fluctuating blood pressure can cause concomitant fluctuation in amplitude of the wave forms.

Halogenated anaesthetic agents can diminish or abolish wave forms. Isoflurane is the halogenated anaesthetic agent used. The concentration administered is kept constant during the period when temporary and permanent clips are being used.

Adequate neuromuscular blockage is essential during monitoring as it removes substantial amounts of unwanted muscle artifact. The train of four is utilized during surgery to monitor and maintain the degree of muscle paralysis.

## **Parameters monitored in the application of SSEPs in aneurysm surgery**

A number of investigators have reported their experience with evoked potential monitoring during aneurysm surgery. A review of literature shows that almost all clinical studies evaluating the use of evoked potential monitoring were prospective case series. There was one trial that used pre-operative SSEP readings as controls.<sup>7</sup>

Symon et. al.<sup>8</sup> were the first group to suggest its utility in a report of 33 monitored cases in 1984. Buchthal<sup>9</sup> and colleagues reported their experience with 5 MCA aneurysms. In no case was arterial occlusion continued for more than 3 minutes after a significance disturbance of SSEPs. None of these patients developed deficits.

Complete loss of evoked potentials or a persistent significant change without return to baseline has been correlated with occurrence of postoperative deficits. Friedman et. al.,<sup>10</sup> in a study consisting of 53 surgeries for aneurysms of the middle cerebral artery reported that all the patients who had a significant drop in amplitude following temporary clipping which did not come back to normal and in cases where there was complete loss of signal, developed postoperative deficits. A 50% drop in amplitude was considered significant. Four out of five patients who had a significant change in amplitude which reverted to baseline value, did not develop deficits. Mc. Pherson et. al.<sup>11</sup> reported a case in which

SSEPs disappeared during temporary clipping of a middle cerebral aneurysm and returned after this clip was removed. A dense hemiparesis resulted but resolved over 24 hours.

The other suggested factors predicting postoperative neurological deficit include speed of disappearance and reappearance of the N20 wave. Momma et. al.<sup>12</sup> in a study involving 40 surgeries for aneurysms concluded that if cortical response is sustained for over 3-4 minutes following vascular occlusion, even if it then disappears, permanent neurological deficit is unlikely. Even if the cortical response disappears, the clinical outcome is expected to be good if N20 peak recovers within 20 minutes after recirculation.

There are several alterations during the surgical procedure that can have an effect on somatosensory evoked potentials mentioned in literature. They include removal or adjustment of temporary clips, brain retraction, and dissection around the region of the aneurysm, brain manipulation and change in anaesthetic parameters.

There exists a certain degree of controversy regarding the parameters in SSEP recording that best reflect a change in the perfusion status of the region monitored. Symon et. al. measured amplitude of SSEP and central conduction time (CCT), the time between the N14 peak (recorded at C-2) and the N20 peak (recorded at the cortex) for monitoring 34 procedures. They stated that a prolongation of CCT was more striking and than a change in amplitude was more indicative of hypoperfusion. Friedman et. al.,<sup>13</sup> in two studies comprising 50 and

53 patients found that decrease in amplitude of SSEPs was a sensitive predictor of postoperative neurological dysfunction. Djuric et. al.,<sup>14</sup> in a study comprising 36 patients, concluded that change in amplitude was a more sensitive predictor than CCT.

### **Timing of temporary clip application**

The period of temporary clipping of the parent artery which can be considered “safe” i.e., without producing postoperative deficits has varied from 10 to 20 minutes in different studies. Not only the duration of clipping, but also the time period between clipping and change in SSEP was considered as a significant factor in determining postoperative outcome.

Suzuki et.al., were the first to estimate the maximum safe limits for iatrogenic cerebral ischaemia during surgery and claimed that intermittent reperfusion allowed prolongation of the total time of temporary clipping.

Ljunggren et. Al. reported that middle cerebral artery occlusion was well tolerated up to 20 minutes. Momma et. al.<sup>15</sup> felt that the ICA could be occluded for up to 10 minutes after disappearance of evoked potential waves, provided the disappearance of readings takes more than 2 minutes after temporary clipping and that the MCA could be occluded for up to 10 minutes if there was no significant change in SSEP after application of the temporary clip without producing postoperative neurological deficits. Mizoi et.al.<sup>16</sup> stated that it was possible to continue with temporary vascular occlusion for up to 10 minutes after

the complete disappearance of N20 component, when the amplitude of N20 has gradually decreased over 2 minutes.

### **Temporary clipping without physiological monitoring**

There have been clinical trials that studied the effect, utility and complications of temporary clipping without the use of physiological monitoring. In a prospective case series of 112 cases, Ferch et. al.,<sup>17</sup> analysed the risk factors for ischaemic damage following temporary clipping. Age, higher grade of subarachnoid haemorrhage ( Hunt and Hess), short interval between the ictus and surgery and increased duration of clipping were found to be directly proportional to a greater risk of stroke following surgery. Aneurysmal size and location were not found to have a statistically significant effect on the outcome.

They observed a trend for an increased incidence of stroke in patients in whom temporary vessel occlusion was performed for more than 10 minutes. The mean duration of clipping with producing deficits was 13.6 minutes. This observation was borne out by other clinical studies. Ogilvy et. al.,<sup>18</sup> concluded that in general, 20 minutes was a critical threshold for focal infarction. Samson et. al.,<sup>19</sup> demonstrated that patients tolerated 14 minutes of temporary focal occlusion. No patient in their series who underwent vascular occlusion for longer than 30 minutes failed to have both radiographic and clinical evidence of focal cerebral infarction in the distribution of the artery occluded while all those who had occlusion times less than 10 minutes had no deficits post operatively. Occlusion times of 40 and 60 minutes have been reported but there seems to be

a consensus that the safe limit for occlusion was 20 minutes. The mean duration of vascular occlusion without associated post operative deficits in a study by Jabre et. al.,<sup>20</sup> were 7.2, 11.6 and 4.3 minutes for anterior cerebral, middle cerebral and posterior communicating artery aneurysms respectively.

All of the above trials were conducted using some form of brain protection measure. Cerebral protective agents include pharmacological and physiological means of increasing the brain's ischaemic tolerance such as hypothermia, induced hypertension, barbiturates, some anaesthetic agents like etomidate, isoflurane , propofol, and other medications such as free radical scavengers and mannitol, either alone or in various combinations. These agents may have a significant beneficial effect in the setting of iatrogenic temporary focal ischemia. They act by reducing cellular metabolic demand while maintaining adequate cerebral perfusion.

The vascular territory involved during temporary clipping was not found to be statistically significant in these trials. However the basilar and middle cerebral arteries appeared to be more sensitive to ischaemic injury. The incidence of infarction in distal basilar temporary clipping was 41% and in middle cerebral occlusion, it was 25%. The incidence was lower for anterior cerebral and, posterior communicating and vertebral arteries<sup>15</sup> .



# **RESULTS**

A total of 47 patients were recruited in this study prospectively. Temporary clip was not used in one patient, who was not included in the analysis.

## **DEMOGRAPHIC AND GENERAL DATA**

### **SEX:**

Number of males – 25

Number of females – 21

Male: Female ratio – 1.3 : 1

### **AGE:**

Mean age – 48.8 years. (Range – 21 to 64)

### **Age distribution :**

<b>Age range</b>	<b>Frequency</b>	<b>%</b>
<b>Below 40</b>	<b>8</b>	<b>17</b>
<b>40 – 49</b>	<b>13</b>	<b>27.7</b>
<b>50 – 59</b>	<b>19</b>	<b>42.6</b>
<b>Above 60</b>	<b>6</b>	<b>12.8</b>

### **DISTRIBUTION AMONG ARTERIAL TERRITORIES:**

	<b>Frequency</b>	<b>%</b>
<b>Anterior communicating artery</b>	<b>24</b>	<b>51</b>
<b>Middle cerebral artery</b>	<b>13</b>	<b>27.6</b>
<b>Posterior communicating artery</b>	<b>6</b>	<b>12.2</b>
<b>Ophthalmic artery</b>	<b>3</b>	<b>8</b>
<b>Internal carotid artery bifurcation</b>	<b>1</b>	<b>2</b>

### **GRADE OF SUBARACHNOID HAEMORRHAGE:**

<b>WFNS grade 1</b>	<b>36</b>
<b>WFNS grade 2</b>	<b>6</b>
<b>WFNS grade 3</b>	<b>4</b>
<b>WFNS grade 4</b>	<b>1</b>

### **DURATION BETWEEN ICTUS AND SURGERY:**

Range – 1 day to 7 years

Median – 25 days

## **DECREASE IN AMPLITUDE**

Total no. of clip applications: 93

No. of instances of decrease in amplitude - 29

Average decrease in amplitude – 44.75 %

**Number of patients who had a significant decrease in amplitude – 9**

**Number of deficits – 3**

## **PATIENTS WHO HAD DEFICITS**

### **Case 1**

**Mr. JP** was a 51 year male with a **right A1-ACom aneurysm**, who had an episode of subarachnoid haemorrhage of WFNS grade – 1.

### **Angiographic characteristics :**

12 mm in size, no collateral flow on cross compression, hypoplastic right A1

The aneurysm was filling from the left A1.

He was operated 26 days following the ictus

**Pre-operatively**, he had a right caudate nucleus infarct but no motor deficits clinically.

**Per operatively**, the aneurysm was found arising from the left A1 – Acom junction. There was a perforator arising from the anterior communicating artery adjacent to this junction. There was a 60% decrease in amplitude of SSEP 3 minutes after temporary clip application on the left A1. The temporary clip was immediately removed. It took 7 minutes for the amplitude to recover to baseline value. The perforator artery was sacrificed in the process of application of the permanent clip.

**Post operatively**, he developed an infarct of the head of the right caudate nucleus. The decrease in amplitude could be attributed to the inadvertent inclusion of the perforator artery during application of the temporary clip. There was no supply from the opposite side because of a hypoplastic right A1 artery, which could be another contributory factor.

## **Case 2**

**Mr. UP**, a 57 year male with a **giant ACom aneurysm**,

### **Angiographic characteristics**

26 mm in diameter,

Type 2 circulation with both the A2 arteries filling from both sides,

Good cross flow.

Operated 66 days following ictus

Temporary clip was applied for 32 and 30 minutes on the left and right A1 respectively. There was **intraoperative rupture** of the aneurysm on attempting to apply a permanent clip. After rupture, temporary clips were applied on the left and right A2s for 10 and 18 minutes respectively, before bleeding was controlled and a permanent clip applied. There was no significant decrease in amplitude.

**Post operatively**, the patient developed right hemiparesis. CT brain showed a **left caudate nucleus and anterior limb of left internal capsule infarct**. CT brain on the seventh post operative day showed bilateral medial frontal lobe infarcts as well. The patient had **clinical features of a bilateral supplementary motor area syndrome**. Motor power showed gradual improvement. He was discharged with residual right hemiparesis and hemineglect on the right side.

In this case, there was no change in the amplitude of evoked potentials, despite clipping of both the A1 and A2 arteries bilaterally. Post operatively, the patient went on to develop bilateral infarcts – an instance of a false negative test. One may infer that in cases warranting bilateral clipping, thus preventing collateral supply from the opposite side, intermittent perfusion would be a better option even if SSEPs are normal, if operating conditions permit.

### **Case 3**

**Ms. P**, a 64 year female with a **left posterior communicating artery** aneurysm

#### **Angiographic characteristics**

4 mm in diameter, with a narrow neck.

The circulation was of type 1

Good cross-flow on cross compression study.

She was operated 30 days following subarachnoid haemorrhage.

**Per operatively**, a temporary clip was placed on the left internal carotid artery.

During dissection around the aneurysm, it was found to have a friable wall, and there was an **intraoperative rupture**. The aneurysm was completely severed from the parent artery. There was a 100% loss of SSEP readings immediately, first on the left side and then on both sides after the patient developed hypotension. The SSEPs were restored back to normal after 36 minutes, after control of the bleeding from the ICA using a right angled fenestrated clip and control of hypotension. Post operatively, the patient remained comatose, with a GCS score of 2t/15.

### **Calculation of specificity and negative predictive value:**

Sensitivity, specificity, positive and negative predictive values were calculated, considering a significant decrease in amplitude to be a positive test and post operative motor deficit as the positive end point.

Based on literature,<sup>21 22 23</sup> significant decreases in amplitude which did not recover to baseline or only partially recovered (Type 4 readings) were associated with postoperative deficits. In this study there were no patients who had such readings. All the SSEP readings which showed a significant decrease in amplitude showed complete recovery to baseline (Type 2 reading). Calculation of sensitivity and positive predictive value cannot be done, therefore in this patient population. None of the patients who did not have post operative deficits had a drop in amplitude which did not recover.

Number of patients who had a post operative deficit but no (type 4) change in amplitude – 3

Number of patients who had no post operative deficits and no (type 4) change in amplitude (true negative) - 43

Number of patients who had no deficits – 43

**Specificity = Number of patients who had no post operative deficits and no (type 4) change in amplitude (true negative) / Number of patients who had no deficits**

The calculated **specificity would therefore be 100%.**

Total number of patients who had no (type 4) change in amplitude - 46

**Negative predictive value = no. of readings showing no change in amplitude and no deficits (true negatives) / total no. of readings showing no change**

The calculated **negative predictive value was 94%.**

The low number of a positive end points (patients with post operative motor deficit) and the presence of a major confounding factor (intra operative rupture), the population of patients who developed deficits post operatively does not lend itself to meaningful statistical analysis. It becomes important therefore, to study the patient population that did develop a significant drop in amplitude as a separate subgroup, irrespective of the postoperative outcome.

## **PATIENTS WHO HAD SIGNIFICANT DECREASE IN AMPLITUDE**

Experimental data has demonstrated the blunting effect of ischaemia on somatosensory evoked potentials. Clinical trials in literature have confirmed this observation by studying the association between a significant decrease in amplitude and post operative ischaemic deficits. These studies showed that post operative ischaemic sequelae occurred only if there was a significant decrease in amplitude which did not come back to baseline. There were no recorded deficits



among those whose amplitudes returned to baseline, either spontaneously or after correction of the cause of the amplitude drop, which in most instances was removal of the temporary clip. A study by Mizoi et.al. Stated that it was possible to continue with temporary vascular occlusion for up to 10 minutes after the complete disappearance of N20 component, provided the amplitude of N20 had gradually decreased over 2 minutes.

In the light of the above evidence it may be assumed with some confidence that a significant drop in amplitude during surgery is due to some form of ischaemia induced by the temporary clip. It becomes important therefore to identify the factors if any that may prognosticate amplitude drop. In this study, the temporary clip was removed by the surgeon immediately after being informed about a significant decrease in amplitude. In all cases of a significant drop, there was return to baseline after removal of the clip. Of these, only one patient developed a deficit. She did not regain consciousness post operatively. The amplitude in this patient stayed below 50% of baseline for about 36 minutes.

Patients are divided into two groups for comparison.

**Group A** - those who showed a significant decrease in amplitude

**Group B** - those who did not have a significant decrease in amplitude

1. **No. of patients** who had a significant decrease in amplitude – 9

2. **Mean age** –

Group A - 51 years (range 40 – 64)

Group B - 48.5 (range 21 – 68)

3. **Sex ratio** - males : females

Group A – 1 : 2

Group B – 1.3 : 1

Females outnumber males by a factor of 2. In contrast, there are more males than there are females in group B. Males predominate over females in the overall sex ratio and when calculated for different ranges of decrease in amplitude below 50%. This was not statistically significant.

4. **Temporary clip application:**

Number of clip applications - 20

No. of instances of change in amplitude – 11

## **5. Site of aneurysm**

Anterior cerebral artery – 4 (16.6% of all ACA aneurysms)

Middle cerebral artery – 4 (30.7 % of all MCA aneurysms)

Posterior communicating artery – 1 (16.7 % of all P. COM artery aneurysms)

A little less than one third of MCA aneurysms showed a significant change in amplitude, compared to other arterial territories. This was not statistically significant.

## **6. Time interval between ictus and surgery**

Median – 24 days. (Group A)

Median – 25 days (group B)

33% of patients in group B were operated within 7 days compared to 13% in group A.

A greater proportion of patients among those who had a significant decrease in amplitude (Group A) seem to have been operated early, (within one week) compared to those who did not have significant change. This was not statistically significant. ( $p=0.13$ )

## **7. Temporary clipping**

6 out of 8 patients (75%) had a significant drop in amplitude during the first clip application. Of these, one patient with an MCA artery aneurysm had a significant drop in amplitude thrice during surgery. There were two patients who had a significant amplitude drop during the second and third clip application.

Among all the patients, 44.7% (21 of 47) had a decrease in amplitude (including 'significant' and lesser) during the first clip application. The percentage of patients who had a decrease in amplitude during the second third and fourth clipping was 18% (4 of 22).

### **PREVALENCE OF SSEP CHANGE**

It is the proportion of the number of instances of a significant change out of the total number of clip applications in a specified subgroup expressed as a percentage. This gives an assessment of the predilection of a particular arterial territory for developing a significant decrease in amplitude during temporary clipping. In other words, it is a measure of the odds of having a significant decrease in amplitude per application of a temporary clip, for each arterial territory.

This excludes readings of patients who had intraoperative rupture since this was strongly associated with and acted as an independent factor producing a significant decrease in amplitude.

### **Prevalence of SSEP change: comparison between arterial territories**

Anterior cerebral artery = **4.25%** (2/47 – 2 significant changes in amplitude out of 47 clip applications)

Middle cerebral artery = **27.3%** (6/22 – 6 significant changes in amplitude out of 22 clip applications)

The prevalence is much lower in ACA territory aneurysms compared to those in the MCA territory . This is because despite temporary clipping of the A1 segment during surgery, cross flow from the opposite side, when present, can perfuse the territory occluded. On the other hand, the M1 arterial segment occlusion is similar to occlusion of an end-artery with no prospects of supply from the opposite side. To negate this factor and therefore provide a better comparison, the patients with ACA aneurysms who had a good cross-flow were analyzed separate from those who did not have cross-flow from the opposite side.

## **Prevalence of SSEP change among ACA aneurysms:**

ACA with good collateral supply - 4.3 %

ACA without collateral supply - 5.5 %

The prevalence of SSEP change in ACA territory without collateral supply was still found to be much more than that of MCA territory and almost statistically significant ( $p=0.07$ ).

## **Prevalence of SSEP change: comparison between sexes**

There were two males and three female patients with intraoperative rupture of aneurysm who were excluded.

Female - **22.2 %** (6 / 27)

Male - **3.9 %** ( 2/51 )

Females were found to be more prone to have a significant change in amplitude. This was statistically significant ( $p=0.01$ ).

The number of clippings in the female subgroup was much lesser than the male subgroup. This probably explains the significant decrease in the ratio

among females. However the actual number of instances of a significant change was still more in females (6 changes) than males (2 changes).

## **SSEP CHANGES AMONG THOSE WHO HAD INTRAOPERATIVE** **ANEURYSMAL RUPTURE**

### **1. Decrease in amplitude:**

No. of patients who had significant decrease – 3

Of these, one patient had a 63% drop in amplitude after application of a permanent clip, which lasted for 2 minutes and improved spontaneously.

### **2. Number of clip applications – 11**

No. of instances of decrease in amplitude – 5

One patient had a 33% decrease in amplitude.

Average decrease in amplitude – **61.25 %**.

**Prevalence of SSEP change : 45.5 % (5 out of 11)**

### **7. Angiographic characteristics**

Size of aneurysms – 4 to 26 mm

Average size – 12.8 mm

## **8. Collateral flow**

Four patients had good collateral supply; one had no supply from the opposite side.

## **Case description:**

Ms. P was a 64 year old lady with a **left posterior communicating artery – ICA junction aneurysm**, with good collateral supply, WFNS grade 3 subarachnoid haemorrhage and Fisher grade 4 subarachnoid haemorrhage on CT scan.

During opening of the sylvian cistern in the region of the IC bifurcation, there was rupture of the aneurysm. The rupture occurred although manipulation was being done in the arachnoid over the sylvian fissure and no manipulation of the artery was performed at that point. This was probably because of the friable nature of the aneurysm wall. Temporary clips were placed on the proximal and distal ACA to control the haemorrhage. It was then realized that the aneurysm had completely severed from the parent artery and it was an end-on tear of the ICA. A right angled fenestrated clip was used to close the opening in the ICA with which the haemorrhage was brought under control. During this period, there was hypotension and there was complete loss of SSEP readings, first on the right



side then bilaterally, which picked up after 36 minutes. This patient did not wake up after surgery and was taken home at request.

## **ANEURYSMS ACCORDING TO ARTERIAL TERRITORY**

### **Anterior Cerebral artery**

Number of cases – 24

There were 9 female and 15 male patients. Male : female ratio – 3:5

#### **Distribution by WFNS grade**

Grade 1 – 18

Grade 2 – 2

Grade 3 – 3

Grade 4 - 1

### **Radiological features**

#### **Size of aneurysms:**

Range – 3 – 26 mm

Average diameter – 8.3 mm

**Fisher grade:**

Grade 1 – 1

Grade 2 – 4

Grade 3 – 16

Grade 4 – 2

CT was done one month after ictus for one patient and it was normal.

**Collateral supply:**

This refers to collateral supply from the opposite side as demonstrated by cross compression study in digital subtraction angiograms. Cross-compression was done in 22 patients. Eleven among these had a good collateral supply and eleven had no collateral supply. Cross compression was not done in two patients.

**Patients with good collateral blood supply:**

Of the eleven patients, only 1 (9%) had a significant decrease in amplitude. The others had either no change or a less than significant decrease in amplitude.

**Prevalence of SSEP change – 4.3 %**

There were four instances of a decrease in amplitude altogether, though all less than significant.

### **Time for recovery**

The **average time for recovery** following a decrease in amplitude, whether significant or not = 4 minutes

### **Patients with no collateral supply:**

There were 2 (18%) patients with significant decrease within this group. There was one more patient who had a brief though significant drop in amplitude following application of a permanent clip. There was bilateral decrease in amplitude in this case.

Patients with less than significant or no decrease = 8 (72%)

### **Prevalence of SSEP change – 5.5 %**

It is interesting to note that this value is not significantly different from the group with good collateral supply.

### **Time for recovery**

The **average time** taken to recover following a decrease in amplitude, whether significant or not = 9 minutes

This was more than double the group with good collateral supply. This was however not statistically significant ( $p=0.28$ , 95% confidence interval -5 to 15.3).

In comparison, there were 9 instances of a decrease in amplitude (significant or not) among **patients with MCA aneurysms**. The average recovery time was 7.44 which was not significantly different from this group. ( $p=0.6$ , 95% confidence interval -10.8 to 7.44).

### **MIDDLE CEREBRAL ARTERY ANEURYSMS**

Number of cases – 13

There were 6 female and 7 male patients. Male : female ratio – 1:1.1

#### **Distribution by WFNS grade**

Grade 1 – 11

Grade 2 – 2

## **Radiological features:**

**Size of aneurysms:** Range – 4 – 15 mm

Average diameter – 9 mm

## **Collateral supply:**

Cross-compression was done in 5 patients. All of them had a good collateral supply.

## **Fisher grade:**

Grade 0 - 1

Grade 1 – 1

Grade 2 – 0

Grade 3 – 10

Grade 4 – 1

## **Temporary clipping:**

Temporary clip was applied a total of 23 times.

There were eleven instances of decrease in amplitude. Out of these a significant decrease in amplitude was recorded six times. Two patients had decrease in amplitudes by 43% and 45%.

**Prevalence of SSEP change = 27.3 %**

Average recovery time – 7.2 seconds

## **POSTERIOR COMMUNICATING ARTERY ANEURYSMS**

Number of cases – 6

There were 4 female and 2 male patients. Male : female ratio – 1:2

### **Distribution by WFNS grade**

Grade 1 – 4

Grade 2 – 1

GRADE 3 – 1

### **Radiological features:**

**Size of aneurysms:** Range – 4 – 23 mm

Average diameter – 10.8 mm

### **Collateral supply:**

Cross-compression was done in 4 patients. Three among these had a good collateral supply.

**Fisher grade:**

Grade 1 – 1

Grade 2 – 0

Grade 3 – 3

Grade 4 – 2

**Temporary clipping:**

Temporary clip was applied a total of 13 times. Out of these a significant decrease in amplitude was recorded once in one patient. This was following an aneurysmal rupture.

Thus the prevalence of SSEP change would be 7.7%. This could be explained by the fact that the ICA was used as the site of temporary clip in most of the cases and collateral supply was good in most (3 of 4) cases. With a good collateral supply, a temporary clip applied to the ICA would not endanger the blood supply to the other arterial territories, especially the MCA and ACA territories.

In the one case where there was a significant decrease in amplitude, this was following rupture of the aneurysm. Temporary clips were applied to the proximal and distal ICA for 30 minutes before control of the bleeding was achieved.

Salient features:

The average diameter was the largest among the four arteries considered.

The rate of significant drop in SSEP amplitude is least among the arterial groups studied. There is a 100% absence of any significant change if the change following the peroperative rupture is not considered.

## **DURATION OF CLIPPING:**

### **Anterior cerebral artery**

less than 5 minutes	- 36 times	(15 patients)
5-9 minutes	- 9 times	(5 patients)
10 minutes and above –	7 times	(4 patients)

### **Middle cerebral artery**

less than 5 minutes	–17 times	(2 patients)
5-9 minutes	- 4 times	(3 patients)
10 minutes and above –	5 times	(1 patient)



### **Posterior communicating artery**

less than 5 minutes – 7 times (1 patient )

5-9 minutes - 2 times (1 patient)

10 minutes and above – 2 times (2 patients)

### **No. of patients with significant changes within specific durations**

**10 minutes and above** – 2 patients , one ACA and one MCA

Of these , one of the patients, with ACA aneurysm had intraoperative rupture and had temporary clip application durations of 30 and 36 minutes. He died on the second post operative day after deterioration in sensorium.

The other patient had clip durations of 13,12,16,13 and 20 minutes with a significant change after the third clip application. The patient had no post operative deficits.

### **5-9 minutes**

There were no patients who had significant change in amplitude.

### **< 5 minutes**

There were 4 patients who had significant change.

This is accounted for by the fact that in all these patients, the decrease in amplitude was within 1 to 2 minutes following clip application after which the clip was immediately removed.

One of them, a patient with an ACA aneurysm had a post operative deficit.

Another patient with an MCA aneurysm had 3 clip applications, each followed by a significant change.

## DISCUSSION

This study included 46 patients who ruptured aneurysms who had been admitted for surgery. All these patients had temporary clip application for proximal control during dissection and permanent clip application. The study was evaluated based on certain premises – that the motor deficit due to the temporary clip must manifest itself within the first 24 hours after surgery and that though SSEP monitoring is a sensory pathway evaluation, the sensory pathway being monitored has a cortical representation which parallels the motor supply of the particular region since both are supplied by the same artery (anterior cerebral artery – lower limb, middle cerebral artery – upper limb). Hence motor system deficits reflect a disruption of the somatosensory pathway due to ischaemia.

There were 9 patients who had a significant decrease in amplitude. All these reading returned to baseline values, even those that disappeared completely for as long as 30 minutes. The lack of readings that have been found to be consistently associated with postoperative deficits, among published case series (i.e., significant decrease in amplitude without return to baseline), prevents the calculation of sensitivity and positive predictive value. The **high negative predictive value (95%)** is of significant interest, however. It is significant because it indicates that in the absence of a significant change in amplitude, the surgeon may be reasonably sure of adequate perfusion in the territory of the artery to which the temporary clip was applied. This is a reassuring

element during the tense period of dissection around the aneurysm following application of the temporary clip.

The temporary clip was removed immediately after a significant change in amplitude signaling ischaemia. The almost immediate restoration of blood supply in this manner ensured that the ischaemia was only transient and this explains the absence of SSEP readings which persisted below 50% of the baseline value. Hence removal of the temporary clip immediately following a significant decrease in amplitude is a very important surgical strategy to avoid ischaemia. Studies have been done where the temporary clip was not removed after a significant drop in amplitude. The authors concluded that the artery may be kept occluded for up to 10 minutes, provided the fall in amplitude took more than 1 minute following application of the clip, without the risk of post operative deficits. This is however not advisable in since the risk of irreversible motor deficits post operatively can be a disastrous event for the patient concerned. The institutional policy of immediate removal of the temporary clip is what is commonly followed among surgeons using this modality of monitoring.

The high negative predictive value and specificity also mean that the temporary clip may be kept applied for longer periods without the fear of conferring a post operative deficit. Periods of more than 5 minutes were frequent in this study population, the maximum being 20 minutes without causing a significant change or postoperative deficit. Clip duration of 30 and 36 minutes

resulted in post operative deficits in one patient. This was during the period of intraoperative aneurysmal rupture of a giant aneurysm.

Only three patients had post operative deficits according to the definition of the study. Of these, per operative rupture occurred in two, a condition associated with significant morbidity of its own and acting as an independent causative factor for ischaemia (and therefore a significant change), apart from the application of the temporary clip.

The above observations indicate that monitoring of SSEPs during surgery may be considered a protective measure against ischaemia during temporary clipping by alerting the surgeon to an ischaemic episode with the potential to become a full-blown infarct, and prompting reparative measures like removal or readjustment of the temporary clip.

### **Limitations of SSEP monitoring:**

Amplitude and latency values during SSEP monitoring are a reflection of the integrity of the somatosensory pathways and any change is indicative of ischaemia in these pathways only. SSEP monitoring does not therefore pick up ischaemia to internal capsule and cortical areas and pathways pertaining to speech as a result of arterial occlusion. SSEP readings may be normal in the event of the patient having developed speech problems or an internal capsule stroke.

## **Analysis of patients who had a significant change in amplitude:**

### **Age:**

The average age of patients in the entire study population was about 48 years. The average age of the subgroup without significant change, the group with significant change and the patients who had intraoperative aneurysmal rupture were 48, 51 and 53 years respectively (Graph 1). There appears to be a trend towards increased age, though not statistically significant, among patients having significant change in amplitude following temporary clip application and intraoperative rupture. The maximum mean age in the group of patients who had intraoperative rupture. Age was the only significant predictor of outcome in surgically treated aneurysms in the International study of unruptured aneurysms.<sup>24 25</sup> The rates of surgical morbidity and mortality in that study were significantly lesser in the younger age group than for older patients.

### **Sex:**

Males outnumbered females by a small margin in the total study population and in the subgroup of patients who did not have any significant decrease in amplitude. In the subgroup of patients who had a significant decrease in amplitude however, there were twice as many females as there were males. This was not statistically significant. When looking at the actual number of temporary clip applications, females were found to have a greater number of instances of significant change compared to males (six in females and two in males). The

clipping : change ratio obtained showed a statistically significant decrease in the ratio in females compared to males, suggesting that females were more prone to a significant change in amplitude than males. Although the actual number of instances of significant change was thrice as common in females than male patients, the disparity in the ratios could be explained by the comparatively decreased number of clip applications among female patients (thus decreasing the numerator).

#### **Temporary clip application:**

A temporary clip was applied 20 times in the group of patients with significant decrease in amplitude, with 11 instances of a significant change among them.

The average decrease in amplitude was, as expected, significantly greater in the group that showed a significant change (67.6%) compared to those who did not show a significant decrease in amplitude during surgery (6.7%).

#### **Comparison among arterial territories:**

A greater proportion **(30%) of MCA aneurysms showed a significant change in amplitude compared to the other arterial territories (16% of anterior cerebral artery aneurysms)** (Graph 2). This probably indicates that MCA aneurysms are more prone to ischaemia during temporary clipping. This

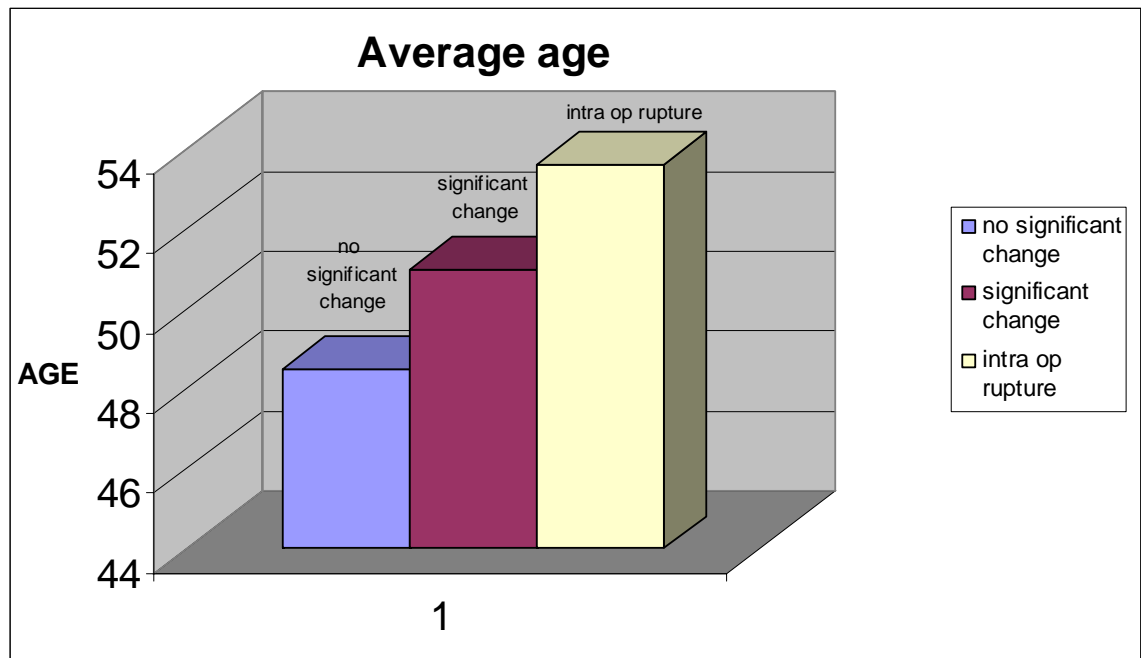
can be explained by the fact that the artery clipped in MCA aneurysm surgery is the M1 segment which is an end artery, whereas clipping of the A1 segment of an ACA aneurysm does not necessarily completely cut off perfusion as it may procure collateral supply from the opposite side, when available. This has been reported by other authors as well though it did not show statistical significance, in this study.

On analyzing the difference between arterial territories by accounting for the actual number of clip applications and instances of significant change, the **prevalence of SSEP change in MCA aneurysms (27.3 %) was higher compared to ACA aneurysms without collateral supply from the opposite side (5.5 %) (Graph 3).** This was found to be almost statistically significant ( $p=0.07$ ).

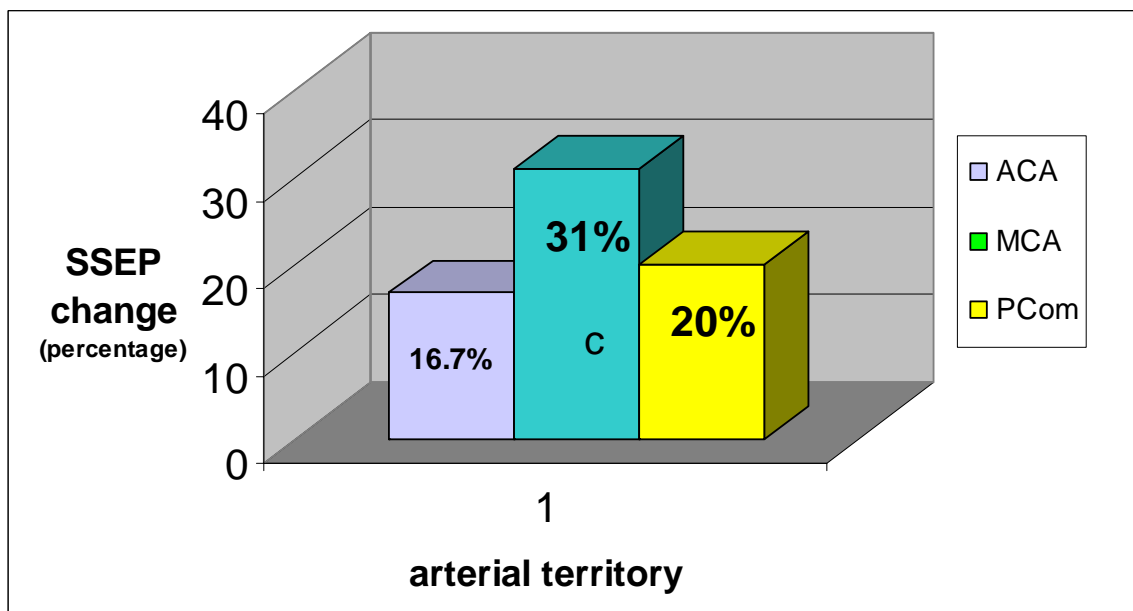
The prevalence of SSEP change indicates that each clip application is associated with a **28% risk of a significant decrease in amplitude in MCA aneurysms as compared to 5% in ACA aneurysms without collateral supply.** In this subgroup of ACA and MCA aneurysms, only one patient with an ACA aneurysm developed a post operative motor deficit.



**Graph 1: Average age**



**Graph 2: Percentage of SSEP change**



### **Comparison with literature:**

In a series of 121 patients who underwent aneurysm surgery, Samson et al.,<sup>26</sup> reported the results of the effect of temporary clipping. There was no form of physiological monitoring during the period of clip application. Of the specific vascular territories undergoing temporary occlusion, the basilar and middle cerebral arteries appeared to be the most sensitive to ischemic injury. 26% of middle cerebral artery aneurysms and 16% of anterior cerebral artery aneurysms developed post operative infarctions. **These figures are almost similar to the percentages of arterial territories that had a significant change in amplitude.** Though not statistically significant in this study, these **proportions could well indicate the number of patients who could have potentially developed a post operative infarct, but were protected from the same because of a surgical intervention in the form of removal of the temporary clip as soon as there was a 50% decrease in amplitude of the monitored evoked potentials.**

### **Time interval between ictus and surgery**

The median number of days between a subarachnoid ictus and surgery was almost the same between the two groups of patients, those who had a significant change in amplitude(group A) and those who did not (group B).

However, **a greater proportion of patients among those who had a significant decrease in amplitude seem to have been operated early, (within one week) compared to those who did not have significant change.** 33% of patients in group B were operated within 7 days compared to 13% in group A. This was not statistically significant. ( $p=0.13$ ), however.

To assess the indications for early or delayed surgery, the International Study on the Timing of Aneurysm Surgery (ISTAS) <sup>27 28</sup> was launched in the early 1980s. The study was a prospective, observational, epidemiologic survey. Principal outcome measures included the patient's neurological status at 6 months, rates of vasospasm and rebleeding, surgical and medical complications during hospitalization. The pros of early surgery were prevention of rebleeding, aggressive management of vasospasm (hypertensive-hypervolemic therapy), removal of subarachnoid clot, and prevention of hydrocephalus and more effective prevention of medical complications. The cons of early surgery were swollen brain, unstable patient. The difficulty level in surgery was the same in the early and late group.

The overall comparison demonstrated that the mortality associated with intervening events while waiting for delayed surgery nearly equaled the postoperative mortality following early surgery (within 7 days). Similar technical difficulties occurred in early surgery and delayed surgery, though a swollen, tight brain was more frequent in patients operated on acutely.

### **Temporal profile of clip application:**

A significant decrease in amplitude was found to be commoner after the first clip application than after subsequent applications (75%). When considering a decrease in amplitude of any degree, 44% of these occurred during the first clip application. The rest were distributed among the subsequent clip applications. Among patients who had multiple clip applications, a change in amplitude of any degree was almost absent after the third sequential clip application. The maximum number of clip applications was in a patient with an MCA aneurysm. The temporary clip was applied 6 times and there was no significant change.

The decreasing tendency towards a drop in amplitude with each subsequent clip application could probably be the result of tolerance of the cerebral perfusion in the arterial territory after the initial insult. Whether physiological in the form of enhanced autoregulation or perhaps anatomical in the form of opening of small collaterals or a more established collateral supply is a matter of debate, warranting further investigation.

## **Comparison across arterial territories:**

**Anterior cerebral artery aneurysms**, commonly at the junction of the ACom artery with the A1 or A2 segment, formed 52% of the study population. The only giant aneurysm in this study was a left A1-ACom junction aneurysm. The percentage of patients with and without collateral supply as demonstrated by flow from the opposite side on cross-compression study in the angiogram was equally distributed. After excluding patients with intraoperative rupture, there was no significant difference in the number of instances of significant change in amplitude (Graph 4). **Patients with no collateral supply however, took twice as long to recover from a decrease in amplitude of any degree on an average when compared those who had good collateral supply.**

Moreover, among the four patients who had a significant change in amplitude, three had no collateral supply.

**The presence of a good collateral supply therefore appears provides a certain, though not significant degree of protection from transient ischaemia** following temporary clip application. However, the presence of two patients with intraoperative rupture in this group acts as a major confounding factor.

**Middle cerebral artery aneurysms** formed the second largest group, accounting for 28% of the aneurysms in this study. The standout characteristic of this group was the **high rate of a significant decrease in amplitude** when

considering this subgroup as a whole and when the absolute numbers of clip applications were considered. The average time for recovery after a decrease in amplitude of any degree was not very different from the anterior cerebral artery aneurysms.

Posterior communicating artery aneurysms had the largest mean diameter (10mm) among the arterial groups. There was one patient with intraoperative rupture who had a significant change in amplitude. There were no other instances of significant change in this group.

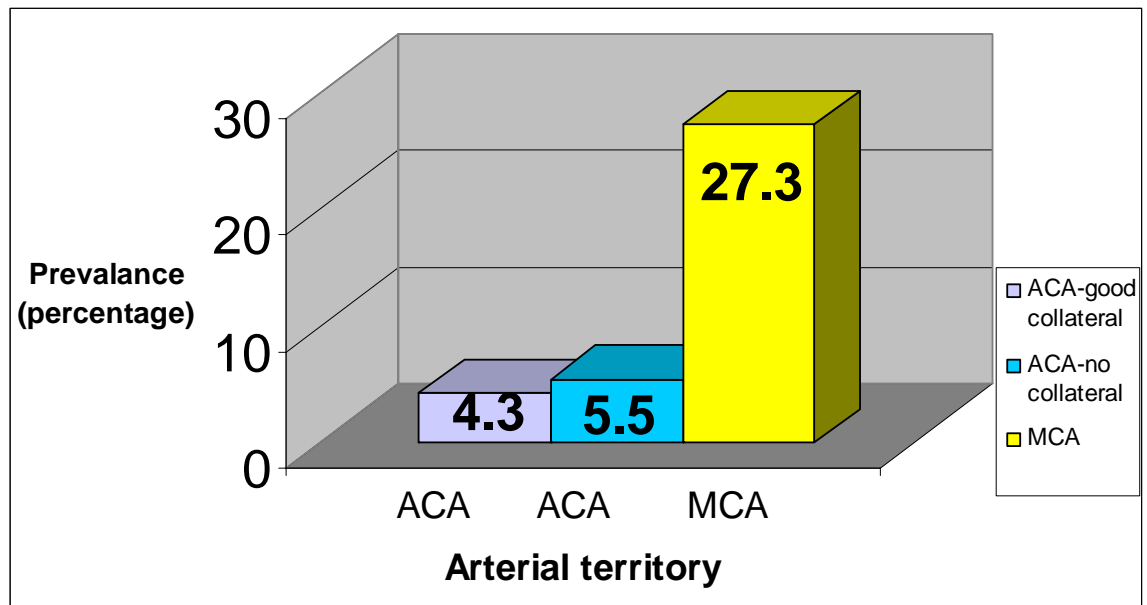
### **Intraoperative rupture of aneurysm:**

This most dreaded complication during surgery occurred in five patients (10.8%). This appears to be **commoner in the older age group**. Intraoperative rupture **accounted for two of the three post operative deficits** in this study and three of the five patients had a significant decrease in amplitude during the course of the surgery, thus acting as a **major intraoperative confounding factor**. It is also significant that the **clipping : change ratio ( 1 : 2.2 ) was the smallest among any subgroup** i.e., there was a 45% risk of a significant change in amplitude after temporary clip application. The average size of these aneurysms was the largest among any subgroup. One patient died, one was discharged with a GCS score of 2/15.

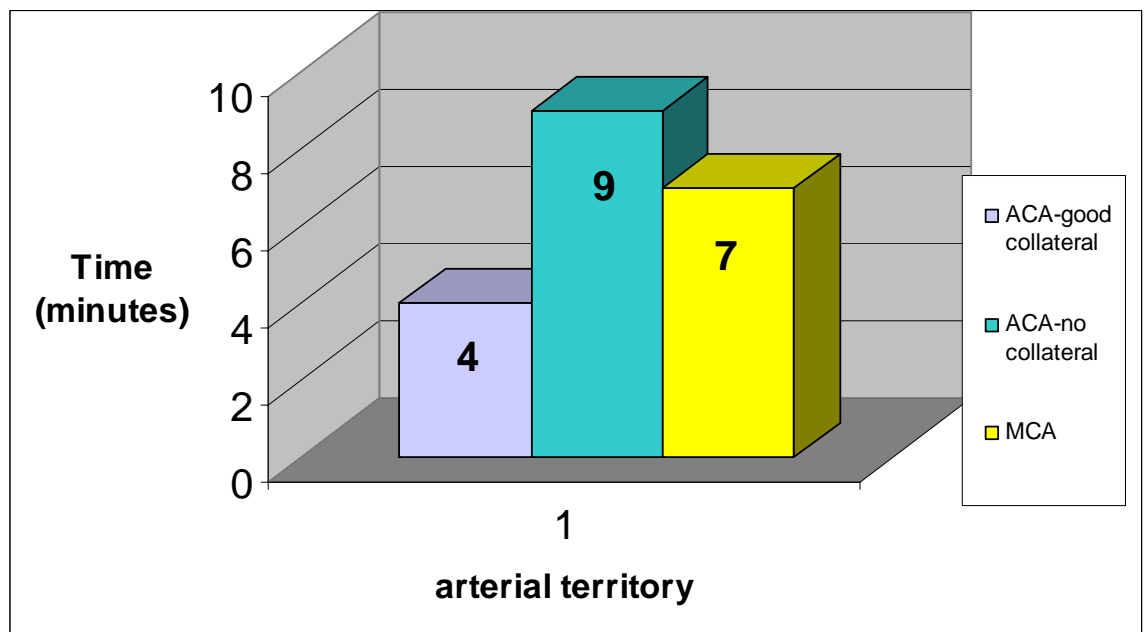
The intraoperative rupture of an intracranial aneurysm is an unexpected and potentially catastrophic event. Aneurysmal rupture ranges in severity from the minor tear in the aneurysmal wall to the complete severance of the aneurysm. The reported incidence ranges from 18% to 60% across different publications<sup>29</sup>. Rupture has been found to occur during three specific periods: (1) early or predissection (7%), (2) dissection around the aneurysm (48%), (3) clip application (45%).

The average duration between the ictus and surgery in this study was 22 days, which was the least among all subgroups (range 2 – 66 days). It is unclear how the timing of surgery affects intraoperative rupture. For example, Kassel et. al., found a similar rate of intraoperative rupture (26%) in patients undergoing early or late surgery. By contrast, Schramm et. al., found that the incidence was twofold more frequent in patients undergoing early surgery (< 3 days, 40%) than in patients undergoing later surgery (20.7%). The therapeutic strategies that have proven useful in dealing with intraoperative bleeding are temporary artery occlusion, tamponade, suction dissection of the aneurysm, clip application to the distal sac, coagulation of the aneurysmal rent and severe induced hypotension.

**Graph 3: Prevalence of SSEP change across arterial territories**



**Graph 4: Recovery time across arterial territories**





## **Duration of temporary arterial occlusion:**

Due to the heterogenous nature of the clipping durations because of personal preference of different surgeons, it is difficult to comment on the maximum safe duration of clip application. Up to 20 minutes of temporary arterial occlusion was tolerated without producing a post operative deficit. Application of a clip for more than 30 minutes was associated with post operative deficit in one patient. There was however intraoperative rupture in this patient which confounds the issue.

The high negative predictive value in this study only means that the likelihood of having ischaemia in the arterial territory occluded is very low in the absence of significant change in amplitude. However there is no positive evidence to show that SSEP monitoring is of any value prospectively and positively. **Does SSEP monitoring, therefore, really help in assessing the state of perfusion of the occluded arterial territory ?**

Despite the absence of type 4 reading (significant decrease in amplitude with no return to baseline, there are indirect pointers that a significant change (type 3 reading) is consistent with ischaemia to the vessel occluded during temporary clip application. These include the following. Average time for return to baseline was higher in patients with ACA aneurysm with no collateral supply, compared to those who had supply from the other side. The proportion of instances of a significant decrease in amplitude within the total number of temporary clip applications (clipping : change ratio) was lower in MCA territory

aneurysm than in ACA aneurysms. It was also lower in ACA aneurysms which did not have collateral supply than compared to those that did. The average decrease in amplitude and time taken for return to baseline after a change in amplitude was maximum in the subgroup of patients who had intraoperative rupture of the aneurysm.

## **CONCLUSIONS:**

1. The **high specificity and negative predictive value** show that SSEP monitoring is a good predictor of patients who will not develop post operative deficits as long as there are no significant changes in amplitude of the waveforms.
2. There is indirect evidence from this study and in comparison with similar studies in literature to show that evoked potential monitoring is an indicator of the state perfusion of an arterial territory and helps avoid potential ischaemia following temporary clip application.
3. Middle cerebral artery aneurysms show a greater propensity to produce ischaemia following temporary clip application compared to other arterial territories.

## **LIMITATIONS OF THIS STUDY**

1. The low number of patients recruited precluded detailed statistical analysis, thus decreasing the statistical power of this study.
2. Confounding factors: There were multiple confounding factors that could produce ischaemia independently, or alter waveforms, and thus affect outcome. The important per operative confounders were aneurysmal rupture, fluctuation in blood pressure, anaesthetic concentrations and depth of muscle relaxation. The major post operative confounder was vasospasm. Other postoperative factors include metabolic abnormalities like hyponatremia causing altered sensorium thus making motor assessment difficult.
3. The patients recruited were not a consecutive series, but rather depended upon the availability of the investigator for a particular surgery. There was no attempt however to selectively include patients.
4. The surgeons involved in this study were a heterogenous group with varying levels of expertise, and different preferences for parameters like duration of temporary clip application.

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## **APPENDIX**

### **1. List of SSEP readings**

1. Right middle cerebral artery aneurysm
2. Right posterior communicating artery aneurysm
3. Right middle cerebral artery aneurysm

**2. Table:** SSEP monitoring in 47 patients (master table)

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